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Effect of large-scale social restriction (PSBB) during COVID-19 on outdoor air quality: Evidence from five cities in DKI Jakarta Province, Indonesia

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ABSTRACT

The variation in the concentration of outdoor air pollutants during the COVID-19 lockdown was studied in Jakarta, Indonesia. The term lockdown was replaced by large-scale social restrictions (PSBB) in Indonesia by more flexible regulations to save the economy. Data on five air pollutants, namely, PM_{10}, SO_2, CO, O_3, and NO_2, from five monitoring stations located in five regions in Jakarta (West, East, Central, North, and South Jakarta) were utilized. We analyzed the changes in the concentrations of outdoor air pollutants before lockdown from January 1 to April 9, 2020, and during lockdown from April 10 to June 4, 2020. Overall, the CO concentration (39.9%) demonstrated the most significant reduction during lockdown, followed by NO_2 (7.5%) and then SO_2 (5.7%). However, we unexpectedly found that during lockdown, the PM_{10} concentration in Jakarta increased by 10.9% due to the southwest monsoon during the seasonal change in Jakarta. Among the five cities in Jakarta, East and Central Jakarta experienced the maximum improvement in their air quality, whereas North Jakarta had the least air quality improvement. To the best of our knowledge, this research is the first to study the effect of lockdown on outdoor air quality improvement in Indonesia using ground-level measurement data. The findings of the study provide additional strategies to the regulatory bodies for the reduction of temporal air pollutants in Jakarta, Indonesia, by restricting people mobility as a supplementary initiative.

1. Introduction

As a country with a high population growth, the transport ownership and energy demand in Indonesia have rapidly increased. Over the past decade, the population density has increased from 132 people/km^2 in 2009 to 144 people/km^2 in 2019 (World Population Review, 2020). In Asia Pacific, the energy demand was expected to increase from 40 quadrillion Btu in 2020 to 55 quadrillion Btu in 2040 (Statista, 2019). The population increase has escalated the transportation demand and harmful gas emissions, leading to air pollution (Frank and Engelke, 2005; Marshall et al., 2005).

DKI Jakarta, the capital of Indonesia, is the fifth most polluted capital city in 2019 (Statista, 2020). This is because DKI Jakarta is the center of mobility and industry in Indonesia. The high levels of air pollution are believed to cause numerous health problems, such as asthma, chronic obstructive pulmonary disease, and acute coronary syndrome (Rizwan et al., 2013). Moreover, a study by the Health Effects Institute (2010) found that transportation facilities pose a great health risk to the populations living within their vicinities.

In 2020, COVID-19 was declared as a pandemic by the World Health Organization (WHO). It is a severe disease caused by a viral infection that attacks the vital organs; it is also highly contagious. The first case of COVID-19 was reported in Wuhan, China, in December 2019. As of October 21, there were 41,273,267 cases with a total death of 1,132,563 (World Health Organization (WHO), 2020). In Indonesia, COVID-19 has significantly affected the economic mobility, industry, companies, environment, and government policy arrangements and caused severe economic losses (Caraka et al., 2020). The high rate of COVID-19 transmission has forced numerous counties, such as China, Italy, and India, to implement lockdowns. However, some countries did not implement lockdowns due to several reasons.

The Ministry of Health of the Republic of Indonesia implemented a large-scale social restriction (PSBB) policy in several big cities, including DKI Jakarta, from April 10 to June 4, 2020. Indonesia did not implement total lockdown due to economic considerations. The government's initiatives to limit people's mobility in order to minimize the spread of

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COVID-19 have been very diverse, such as closing down classrooms and offices, shutting down public transportation, banning public meetings, and implementing the "stay at home" policy (Indonesian Ministry of Health, 2020). The DKI Jakarta PSBB has reduced mobility among people, industrial activities, and mass transportation, thus decreasing the transportation flow and gas emissions from various vehicles.

Several researches have studied the effect of lockdown on air quality in several countries. Wang et al. (2020) and Bao and Zhang (2020) investigated the effect of lockdown on six air pollutants ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and O_3) in northern China. They found that during the lockdown, the air quality improved due to the reduction in emissions from vehicles and secondary industry sectors. Adams (2020) also conducted a research to evaluate the effect of lockdown on air quality in Ontario, Canada. The results revealed that the $PM_{2.5}$ concentration did not change; contrarily, O_3 and NO_2 demonstrated moderate and significant decreases, respectively. Mahato et al. (2020) studied the effect of lockdown amid the COVID-19 pandemic on air quality in Delhi, India. The results revealed that PM_{10} and $PM_{2.5}$ both decreased by 50%, whereas NO_2 and CO decreased by 52.65% and 30.35%, respectively.

Similar research was also conducted in numerous countries, such as Egypt (El-Magd and Zanaty, 2020), Bangladesh (Rahman et al., 2020), Iraq (Hashim et al., 2021), the United Kingdom (Ropkins and Tate, 2021), and the United States (Chen et al., 2020). Different results were obtained; some countries experienced a significant improvement in several air pollutants, whereas others did not. To the best of the author's knowledge, no study on the effect of lockdown on air quality in Indonesia has been conducted yet. Thus, this research aimed to explore and evaluate the changes in outdoor air quality during PSBB in the Province of Jakarta (DKI Jakarta). We hypothesized that PSBB significantly alleviates air pollution in DKI Jakarta. This study evaluates five air pollutants (PM_{10}, SO_2, CO, O_3, and NO_2) in five regions in DKI Jakarta (North, West, East, Central, and South Jakarta).

2. Indonesian large-scale social restriction (PSBB)

The first case of COVID-19 in Indonesia was reported in the first week of March 2020. As an initiative to prevent the spread of COVID-19, the government has announced to implement PSBB or partial lockdown instead of total lockdown. However, PSBB was not implemented in all regions in Indonesia, only in provinces with a high number of cases. DKI Jakarta was the first to implement PSBB, which began on April 10, 2020. PSBB was implemented in 4 provinces and 72 cities (14%) out of a total of nearly 514 cities in Indonesia (Indonesian COVID Handling Committee, 2020). When the cases became manageable, the number of cities that implemented PSBB has continued to decline.

Similar to the implementation of lockdown in other countries, in the first phase of PSBB (April 10 to 4 June 2020), the government has decided to close down all schools and offices (except strategic services, e.g., health, communication, and export and import services, defense and security activities, and basic need provision); implement "work from home" for non-essential services; close down all religious places; ban activities and social and cultural events, including wedding; limit people's mobility to only buying basic needs; and decrease vehicle capacity to only 50%. All rules were established in accordance with the DKI Jakarta Governor Regulation No. 33/2020.

The second phase of PSBB is referred to as transitional PSBB, which was implemented from June 5 to September 13, 2020. It is also known as the new normal phase. Schools and universities were still closed. Non-essential service companies, religious places, public facilities, public transportations, recreational places, and places for sports activities were allowed to open at only 50% capacity. All transitional PSBB regulations were established in accordance with the DKI Jakarta Governor Regulation No. 51/2020. The implementations of PSBB and transitional PSBB were set alternately, depending on the current condition.

3. The study area

DKI Jakarta occupies an area of approximately 664.01 km^2 and is located in the geocoordinate of 6.2088°S, 106.8456 °E (Fig. 1). It has five air quality monitoring stations, with each city having one machine. The stations are located at the Hotel Indonesia Roundabout in Central Jakarta (6.1934°S, 106.8228°E), Kelapa Gading in North Jakarta (6.1614°S, 106.9044°E), Jagakarsa in South Jakarta (6.3339°S, 106.8237°E), Lubang Buaya in East Jakarta (6.2939°S, 106.9034°E), and Kebon Jeruk in West Jakarta (6.1835°S, 106.7647°E). The Hotel Indonesia Roundabout is strategically located in the center of Jakarta which has a high flow of vehicles. The West and East Jakarta were the densest and largest industrial cities in DKI Jakarta (DKI Jakarta Department of Statistic, 2020). However, the DKI Jakarta seaport is located in North Jakarta where trucks and other large loading vehicles are allowed to pass through.

Indonesia ranked 8th among countries with premature mortality linked to outdoor air pollution in 2010 (Lelieveld et al., 2015). As the capital of Indonesia, Jakarta is full of motorized vehicles, and the number of factories is continuously increasing, which also increases the air pollutants. Jakarta has the largest number of vehicles among the cities in Indonesia. According to the Indonesian Department of Statistics (2019), the total number of vehicles in DKI Jakarta is nearly 21 million. Aligned with a high vehicle population, the study by AirVisual IQ (2018) revealed that DKI Jakarta is the most polluted province in Southeast Asia.

The INRIX Global Traffic Scorecard (2019) indicated that Jakarta is the most congested city in Southeast Asia, ranks 2nd in Asia, and ranks 16th worldwide. The main source of air pollution in Jakarta is vehicle exhaust emissions, which account for 57% of the air pollution (Vital Strategies, 2019). During the implementation of PSBB, community mobility has changed, resulting in the reduction of traffic activity. According to COVID-19 community mobility reports (2020), the mobility to retail and recreational places, train stations, and workplaces dropped by 56.01%, 65.96%, and 46.73%, respectively, compared with those during the normal days (Fig. 2). Moreover, the congestion level in DKI Jakarta was reduced by 36% compared with the previous year (Tomtom Traffic Index, 2020). Better traffic condition can be observed in April and May 2020, during which traffic congestion declined by 42% and 38%, respectively.

Jakarta is one of the largest industrial provinces in Indonesia. By the end of 2018, there were 1555 medium-sized manufacturing industries and 563 large-sized industries (Indonesian Department of Statistics, 2018); 35% of them were located in West Jakarta (dominated by food industries), 27% in North Jakarta, 22% in East Jakarta, 9% in South Jakarta, and 7% in Central Jakarta. The automobile industry has the highest gross output value in Jakarta, which is over 9 million USD. During the PSBB period, the automobile production sharply declined from over 100,000 units a month in January–March 2020 to only 21, 000, 2,510, and 17,689 units in April, May, and June, respectively (Indonesia Automotive Industries Association, 2020).Overall, the industrial sector in Indonesia declined by 7.75% in the second trimester of 2020 (Indonesian Ministry of Industry, 2020).

4. Current air pollution reduction initiative in Indonesia and Jakarta Province

The car-free day program is the main initiative of the government to reduce air pollution in Indonesia. It is being implemented in several big cities, including the cities in DKI Jakarta, from 6 a.m. to 11 a.m. on weekends. Through this policy, air pollution can be temporarily reduced to a certain level. However, more congestion and pollution problems can be observed in alternate routes (Farda and Balijepalli, 2018). Meanwhile, during weekdays, an alternative odd–even policy is implemented; this policy restricts vehicle movement based on vehicle registration numbers. For example, vehicles with odd registration numbers only

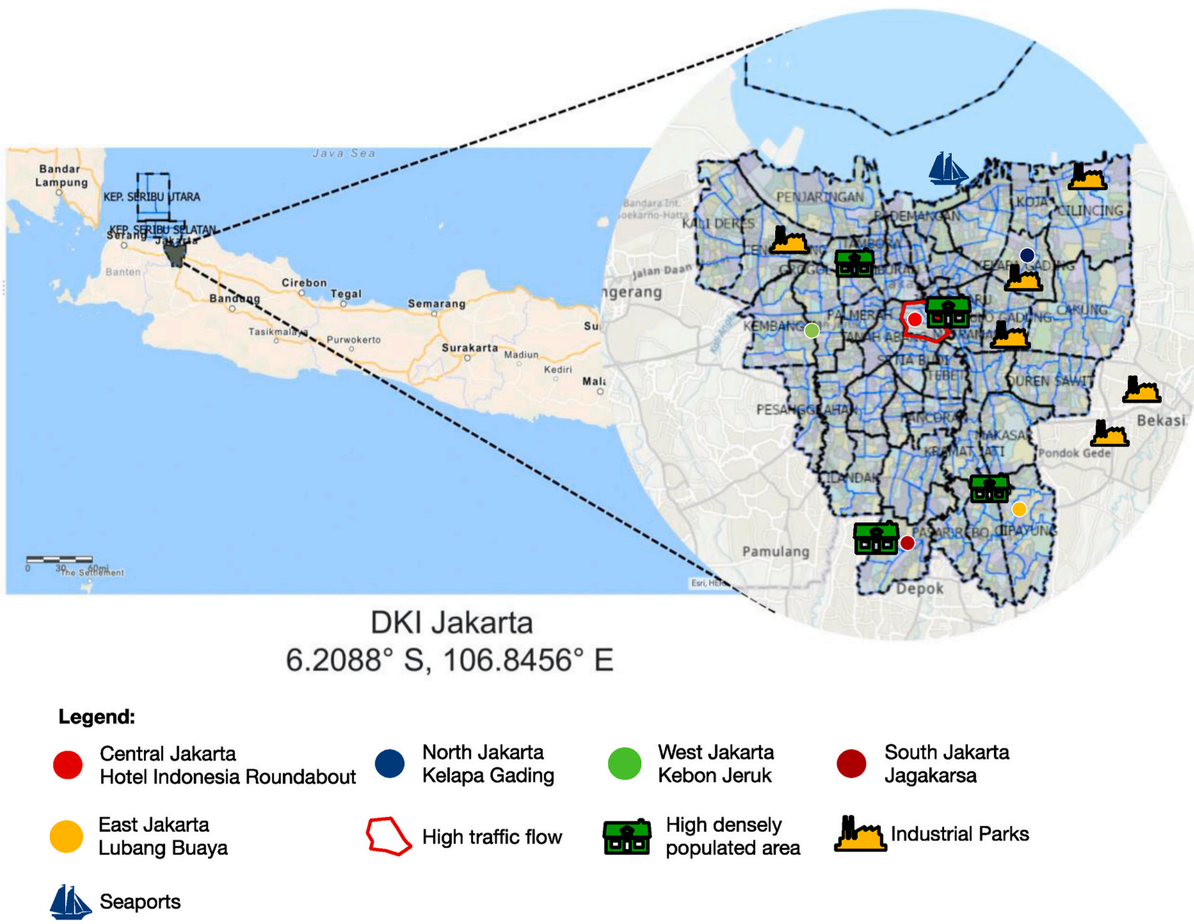

Fig. 1. Reference map of DKI Jakarta Province and its administrative units.

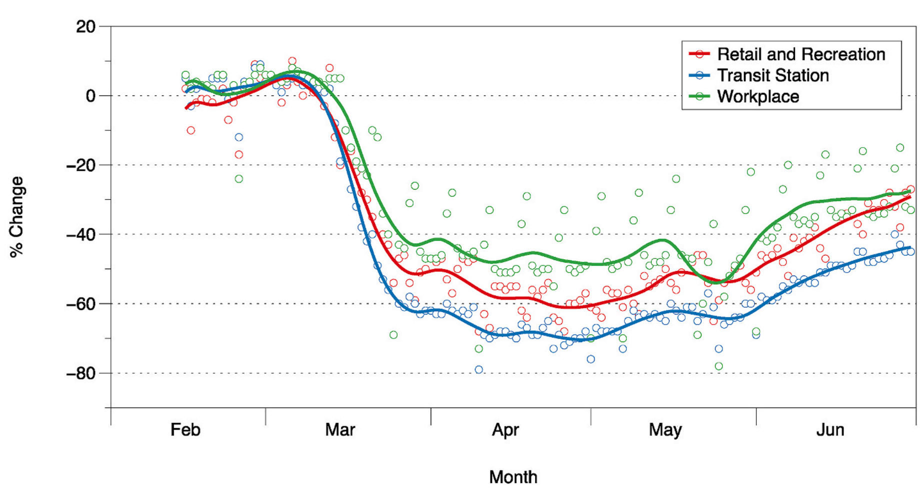

Fig. 2. The mobility trend changes during PSBB in Jakarta from February to June 2020 (Source: COVID-19 community mobility reports, 2020).

operate on odd dates and vice versa. The odd–even policy was shown to be a practical solution; however, drivers started buying more vehicles or using fake vehicle registration plates.

Another initiative to reduce air pollution is by improving public transportation. This policy has been implemented by providing various public transportations, such as paratransit (minibus that can accommodate 12–14 passengers), *TransJakarta* buses, mass rapid transit, commuter line (KRL), and light rail transit. Moreover, the Government of Indonesia has improved several infrastructures to reduce the use of private vehicles, such as sidewalks, pedestrian walk lanes, bike parks, and parking control. Frequent and regular vehicle emission tests were also being conducted to check the eligibility of private vehicles to be on the road (Gunawan et al., 2017).

5. Methodology

To study the impact of large-scale social restriction (PSBB) on air quality, data from five cities in DKI Jakarta, namely, North, South, West, East, and Central Jakarta, were analyzed. Air quality data were collected from the DKI Jakarta Provincial Integrated Data Portal (data.jakarta.go.id) from 2018 to 2020 during the PSBB period (January to June). The data were then divided into three groups: pre-PSBB (January 1 to April 9), during PSBB (April 10 to June 4), and post-PSBB (June 5 to June 30). There were 13,600 available data; the missing data (502 data) were completed *via* interpolation.

Five air pollutants were included in this study, namely, PM_{10}, SO_2, CO, O_3, and NO_2. The air quality in Indonesia is reported using the Air Pollution Index (API) and is derived from the upper and lower limit values of API and real ambient data in μg/m^3. The API is the only official standard in Indonesia for the measurement of air quality at a certain location and time. The conversion of the actual ambient air measurement to API is explained in Equation (1):

$$API = \frac{API_u - API_l}{X_u - X_l}(X - X_l) + API_l \qquad \text{(Eq. 1)}$$

where:

API: air pollution index.
API_u: API upper limit.
API_l: API lower limit.
X: Real ambient air measure.
X_u: Ambient upper limit.
X_l: Ambient lower limit.

The API is categorized into five according to its level of severity: good (1–50), moderate (51–100), unhealthy (101–199), very unhealthy (101–199), and hazardous (300 above). The unhealthy API is harmful to sensitive groups, and the very unhealthy API has serious effects on sensitive groups and the general population (Indonesian Ministry of Environment, 2010). Moreover, the hazardous API is the most severe level and can cause death to a large population. In the next step, the independent sample *t*-test is employed to investigate whether the large-scale social restriction (PSBB) would significantly affect the air quality in Jakarta.

6. Results

6.1. Concentration of air pollutants in DKI jakarta during PSBB and Pre-PSBB

The concentrations of the air pollutants in five cities in DKI Jakarta were non-uniform. The CO concentration significantly decreased, whereas the SO_2 and NO_2 concentrations moderately decreased. Contrarily, the PM_{10} and O_3 concentrations slightly increased. The CO concentration decreased from 21.8 to 13.1 (39.9%), whereas the SO_2 and NO_2 concentrations decreased by 5.7% and 7.5%, respectively (Table 1). Conversely, the PM_{10} and O_3 concentrations increased by 10.9% and 5.9%, respectively, during the PSBB implementation.

About 80% of the air pollutant concentrations statistically changed before and during PSBB (Table 2). In Central and North Jakarta, the concentrations of all the air pollutants were significantly different, whereas in East Jakarta, four out of five air pollutants demonstrated a statistical difference. Moreover, a similar pattern can be observed in West and South Jakarta, where the PM_{10} and O_3 concentrations did not significantly change during the PSBB implementation. The concentrations of SO_2, CO, and NO_2 in all cities were significantly different; for instance, the SO_2 and NO_2 concentrations significantly decreased and increased, respectively.

Table 2
T-Test analysis on the Effect of PSBB on Air Quality.

	Central Jakarta	North Jakarta	South Jakarta	East Jakarta	West Jakarta
PM10	0.000[a]	0.001[a]	0.823	0.019[a]	0.081
SO2	0.000[a]	0.000[a]	0.000[a]	0.002[a]	0.000[a]
CO	0.000[a]	0.001[a]	0.000[a]	0.000[a]	0.000[a]
O3	0.000[a]	0.009[a]	0.536	0.000[a]	0.457
NO2	0.000[a]	0.000[a]	0.000[a]	0.438	0.005[a]

[a] Indicates there is a significant difference in mean concentrations of air pollutants before (1 January – April 9, 2020) and during implementation of PSBB (10 April – June 4, 2020), $p \leq 0.05$.

Among the five cities in DKI Jakarta Province, East Jakarta experienced the greatest improvement in air quality during the PSBB period. In this city, the concentrations of all the air pollutants decreased, except for the PM_{10} concentration, which increased by 13%. In South and Central Jakarta, the concentrations of three pollutants decreased: CO and NO_2 in both cities and SO_2 (concentration decreased by 52%) in Central Jakarta; moreover, the PM_{10} concentration improved by 1% in South Jakarta (Fig. 3). However, only the CO concentration decreased in North Jakarta, whereas the concentrations of other four pollutants increased by 15%–106%.

6.2. Seasonal variation of pollutant gases in 2018–2020

The time series of daily air pollutant concentrations for the ground station in the last 6 months (January–June) from 2018 to 2020 is presented in Fig. 4. The graphs are divided into three periods: pre-PSBB (January 1–April 9), during PSBB (April 10–June 4), and post-PSBB (June 5–30). The PM_{10} concentration always exhibits an increasing trend in the first 6 months of each year from 2018 to 2020. The lowest PM_{10} concentration is observed in January, and it steadily increased until June every year. During the PSBB period, the PM_{10} concentration increased by 7.14% between pre-PSBB and during PSBB and increased by 29.01% between pre-PSBB and post-PSBB. However, in the year over year (YOY) comparison, the PM_{10} concentrations were 3.3%, 15.4%, and 2.4% lower in April, May, and June, respectively, compared with the 2019 data (see Table 3).

PSBB had no impact on the decrease in the SO_2 concentration. In the YOY comparison during the PSBB period (April to June), this pollutant increased by 1.5%, 6.9%, and 4.9% respectively, compared with the data in 2019. However, comparison of the data in 2020 during the pre-PSBB and PSBB periods revealed that the SO_2 concentration decreased from 15.8 to 14.9. In the post-PSBB period, SO_2 continued to increase by 13.47% compared with that in the pre-PSBB period.

CO, O_3, and NO_2 exhibited a downward trend during the implementation of the PSBB in 2020 (Table 3). In DKI Jakarta, the PSBB period was divided into three phases: Phase 1 (April 10–23, 2020), Phase 2 (April 24–May 22, 2020), and Phase 3 (May 23–June 4, 2020).

Table 1
Comparison of air pollutants between Pre-PSBB and during PSBB in five cities of DKI Jakarta.

Pollutants	Pre-Large-scale social restriction (January 1, 2020–April 9, 2020)						Large-scale social restriction (April 10, 2020–June 4, 2020)					
	Central Jakarta	North Jakarta	South Jakarta	East Jakarta	West Jakarta	AVG	Central Jakarta	North Jakarta	South Jakarta	East Jakarta	West Jakarta	AVG
PM10	40.8	46.2	47.7	55.5	42.5	46.5	48.0	53.0	47.3	62.8	46.7	51.6
SO2	11.5	9.1	14.8	26.7	16.7	15.8	5.5	18.7	17.5	23.7	9.0	14.9
CO	18.3	15.3	29.7	20.6	25.3	21.8	6.6	11.5	19.7	15.2	12.5	13.1
O3	37.0	50.6	58.6	72.8	76.9	59.2	48.9	62.2	61.1	57.0	84.1	62.7
NO2	12.4	6.7	7.9	6.1	7.0	8.0	9.2	8.5	5.5	5.8	8.1	7.4

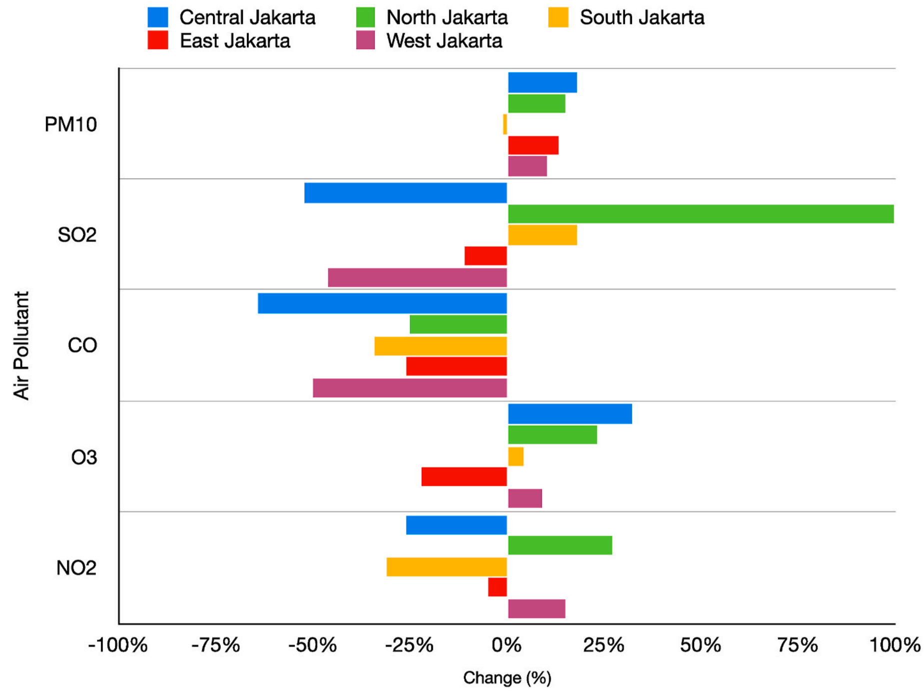

Fig. 3. Changes (%) of PM_{10}, SO_2, CO, O_3, and NO_2 in five cities of DKI Jakarta during PSBB and pre-PSBB.

The Government of DKI Jakarta Province continued to extend the PSBB period in response to the current situation. During the PSBB Phases 1 to 3, the concentrations of CO, O_3, NO_2 decreased by 4.49%, 34.0%, and 11.71%, respectively. In the YOY basis, the CO and NO_2 concentrations exhibited significant decreases in April by 38.0% and 34.6%, respectively. The upward trend was observed in June when the government started to loosen the regulation. However, the O_3 concentration moderately decreased from 67.26 in April to 64.10 in June 2020.

During the post-PSBB period (June 5–30, 2020), the Government of DKI Jakarta announced to loosen PSBB and promote a "new normal" behavior. During the post-PSBB period, all activities continued as usual, but health protocols were followed. The average PM_{10}, SO_2, O_3, and NO_2 concentrations in 2020 reached the highest average in the last 6 months (January–June 2020), even if we compare them with the pre-PSBB period.

7. Discussion

Our analysis was conducted using ground-level measurements of air pollutants that would provide benefit and limitation. The benefit is that the air pollutant measurement data was close to the real breathing height, whereas the limitation is the geographical scope (Adams, 2020). In DKI Jakarta Province, the real air quality monitoring station is located in five cities, with each city having one machine. In this study, each air quality station reveals the real condition of each city.

Our study indicated that three air pollutants, CO, SO_2, and NO_2, decreased by 39.9%, 5.7%, and 7.5%, respectively. However, the PM_{10} concentration in most cities in DKI Jakarta increased during the PSBB period, whereas the O_3 concentration exhibited a mixed trend. These results demonstrated a similar pattern in terms of the air quality reduction worldwide. Kumari and Toshniwal (2020) observed changes in the $PM_{2.5}$, PM_{10}, NO_2, SO_2, and O_3 concentrations in 12 cities across the globe. They found that the concentrations of most of the air pollutants decreased significantly, whereas that of O_3 increased. An increase in the O_3 concentration was also observed in several countries, such as Ecuador (Zambrano-Monserrate and Ruano, 2020), India (Selvam et al., 2020), and Spain (Briz-Redón et al., 2021). In our study, the O_3 concentration increased from 4% to 32% on average in four cities, except in East Jakarta. The increase in the O_3 concentration was caused by the high levels of solar activity during the PSBB period (Kerimray et al., 2020). However, changes in the O_3 concentration could also be influenced by the decline in the emission of NO due to the inverse relationship between them (Kumari and Toshniwal, 2020; Hashim et al., 2021).

No downward trend was observed in the PM_{10} concentration during the PSBB period (April to June 2020) as compared with the pre-PSBB period (January to March 2020). This is an unexpected result as most of the published research revealed a significant decrease in the PM concentrations in many countries, even more than 50% during the lockdown (Otmani et al., 2020; Selvam et al., 2020). However, we found a 15.9% reduction in the PM_{10} concentration in Phase 1 and Phase 3 of PSBB, but the average was still higher compared with that during the pre-PSBB period. This result is non-linear with the fact that the road traffic and industrial exhaust emissions in Indonesia were the main contributors of PM concentrations as high as 46% and 43%, respectively (Vital Strategies, 2020). Even the increase in PM_{10} concentration in Central Jakarta was among the highest, whereas the air quality monitoring machine is located in the roundabout that is usually heavy in traffic.

In the YOY performance, the PM_{10} concentrations decreased moderately, with May demonstrating the highest reduction of 15.4% and a decrease by 3.3% and 2.4% in April and June, respectively, compared with 2019. We also found a consistent upward trend from January to June every year from 2018 to 2020, where the PM_{10} concentration reached its peak in June. Several researchers also found an increase in the PM_{10} concentration during the lockdown period in several countries, such as Ropkins and Tate (2021) and Shakoor et al. (2020). Secondary aerosols are the main components of particulate matter and involve complex atmospheric chemical processes, including emissions of precursors and meteorological conditions (Pei et al., 2020). Several researchers also found that in Southeast Asia, the PM_{10} concentration demonstrated an upward trend and even exceeded the emission standard during the southwest monsoon between April and October (Mohtar et al., 2018; Norazian et al., 2015).

The other air pollutants in this study (CO, SO_2, and NO_2) exhibited a decrease in concentration by 7.5%–39.9%. The major reduction was

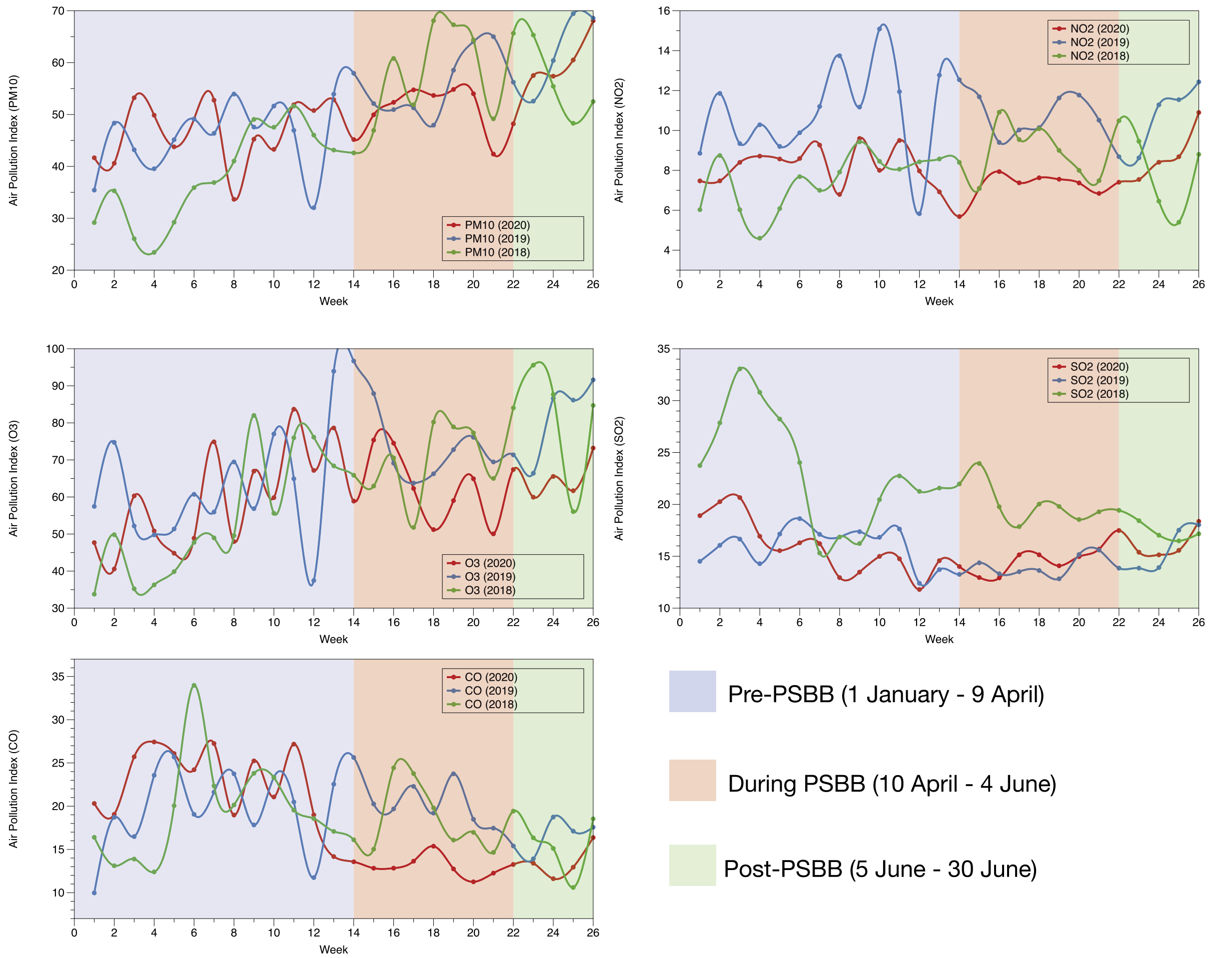

Fig. 4. The daily average concentration of PM_{10}, CO, O_3, NO_2, and SO_2 from five cities in DKI Jakarta between 1 January to 30 June from 2018 to 2020. PSBB measure was imposed on 10 April – 4 June (indicated with a red background), pre-PSBB was imposed on 1 January – 9 April (indicated with a blue background), and post-PSBB was imposed on 5 June – 30 June (indicated with green background). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Average air pollution index in jakarta from 2018 to 2020.

Year	Month	Monthly Average of Air Pollution Index									
		PM_{10}	% change from the previous year	SO_2	% change from the previous year	CO	% change from the previous year	O_3	% change from the previous year	NO_2	% change from the previous year
2018	January	27.77		28.75		13.86		38.06		6.17	
	February	38.08		19.81		25.21		48.83		7.62	
	March	48.40		20.97		20.58		74.46		8.69	
	April	50.35		20.76		19.56		62.55		8.95	
	May	62.97		19.43		17.32		77.39		8.88	
	June	56.22		17.49		15.16		80.12		7.67	
2019	January	41.22	48.4%	15.35	−46.6%	17.43	25.7%	57.65	51.5%	10.06	63.1%
	February	50.12	31.6%	17.60	−11.2%	22.23	−11.8%	59.94	22.7%	11.13	46.0%
	March	45.55	−5.9%	15.51	−26.1%	19.10	−7.2%	65.92	−11.5%	11.34	30.4%
	April	53.06	5.4%	13.64	−34.3%	22.01	12.5%	79.94	27.8%	11.07	23.7%
	May	59.01	−6.3%	14.41	−25.8%	19.16	10.7%	70.14	−9.4%	10.63	19.7%
	June	61.80	9.9%	15.44	−11.7%	16.77	10.6%	82.29	2.7%	10.71	39.5%
2020	January	46.39	12.5%	18.86	22.9%	22.95	31.7%	50.34	−12.7%	8.12	−19.2%
	February	44.66	−10.9%	14.95	−15.1%	24.65	10.9%	54.23	−9.5%	8.38	−24.7%
	March	49.28	8.2%	13.97	−9.9%	20.76	8.7%	73.29	11.2%	8.26	−27.1%
	April	51.29	−3.3%	13.84	1.5%	13.64	−38.0%	67.26	−15.9%	7.24	−34.6%
	May	49.95	−15.4%	15.40	6.9%	12.44	−35.1%	58.80	−16.2%	7.20	−32.3%
	June	60.30	−2.4%	16.20	4.9%	13.55	−19.2%	64.10	−22.1%	8.74	−18.4%

observed in the CO concentration, in which Central and West Jakarta demonstrated a reduction of 64% and 50%, respectively. In DKI Jakarta, land transportation was the major contributor of CO emission, which accounts for up to 93% (Vital Strategies, 2020). This finding is linear with the existing publications that demonstrated that lockdown and social restriction could slow down the transportation activities, thus improving the air quality (Mahato et al., 2020). According to the data from COVID-19 community mobility reports (2020), the transportation activities in Jakarta during the PSBB period dropped to 66%.

No significant improvement in the air quality was observed in North Jakarta. The concentrations of all the air pollutants in this city increased, except that of CO. In North Jakarta, where the sea port is located, the loading activities and flow of large vehicles continued as usual or were slightly restricted during the PSBB period. Large vehicles used to transport food, gas, and industrial tools and for export–import activities were still allowed to operate during the PSBB period. This may have led to an increase in SO_2 concentration due to the sulfur content of petrol and diesel (Lamarque et al., 2010). In addition, two coal-fired power plants in North Jakarta were the reason for the increase in the SO_2 and NO_2 concentrations. During the PSBB period, the coal consumption for the power increased by 9 million tons (CNBC Indonesia, 2020). Moreover, it was reported that several manufacturers of sulfuric acid and aluminum sulfate in North Jakarta did not have an appropriate fireplace, thus mainly contributing to the air pollution in the city (Viva News, 2019).

The reduction in the concentrations of the air pollutants in DKI Jakarta during the PSBB period was temporal. This can be observed from the significant increase in air pollutants after the PSBB period. The average concentration of the air pollutants in the post-PSBB period was even higher compared with that in the pre-PSBB period, except for the CO concentration. However, the large-scale social restriction (PSBB) is one of the solutions to decrease the air pollution problems in DKI Jakarta. For the long-term benefit, the government should improve the currently available public transportation and develop hybrid and more environmentally friendly technologies (e.g., green vehicles) for the public (Purnomo and Anugerah, 2020; Saari et al., 2020).

8. Conclusions

In this study, we investigated the effects of lockdown amid the COVID-19 pandemic on the air quality changes in DKI Jakarta as a result of the restrictions on transportation and industrial activities. A significant reduction of 39.9% on average in the CO concentration was observed in five cities, followed by a moderate reduction in the SO_2 and NO_2 concentrations of 5.7% and 7.5%, respectively. However, we unexpectedly observed that the PM_{10} concentration in DKI Jakarta increased by 10.9% compared with that in the pre-PSBB period. The increase in the PM_{10} concentration in Indonesia was mainly caused by the road traffic and industrial exhaust emissions, which account for 89%. However, the ground-level measurement of the PM_{10} concentration increased during the PSBB period. The increase in the PM_{10} concentration during the PSBB period was mainly due to seasonal variation, in which the PM_{10} concentration tends to be higher in April to October. The concentration of O_3 also increased, but it was expected due to its inverse relationship with NO_2.

Among the five cities in DKI Jakarta, East and Central Jakarta demonstrated an improvement in air quality. The concentrations of all the air pollutants, except PM_{10}, decreased. This was due to the reduction in traffic activities all over Jakarta, especially Central Jakarta, which has the highest flow of transportation among the other cities. Conversely, there was no air quality improvement in North Jakarta, but a reduction in the CO concentration was observed. The SO_2 concentration even increased by 106% due to the high coal consumption for the power plants during the PSBB period.

To the best of the author's knowledge, this research is the first to analyze the effect of lockdown on the air quality changes in Indonesia using ground-level measurement data. The results were accurate because the collected data were close to the real breathing height. The large-scale social restriction (PSBB) can be adopted as one of the temporal strategies to reduce the concentrations of the air pollutants in DKI Jakarta and as a supplementary initiative to existing regulations. A permanent reduction in the air pollutant concentrations in a high-density area like DKI Jakarta needs to be achieved. Most of the published studies on the effect of lockdown on air quality changes were conducted in capital cities or urban areas, including the study on Southeast Asia conducted by Kanniah et al. (2020). However, further investigation in medium-sized and small-sized cities should also be conducted.

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Author's contributions

Adhe Rizky Anugerah: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Supervision. Prafajar Suksessanno Muttaqin: Software, Data curation, Writing – review & editing, Visualization, Funding acquisition. Dwi Adi Purnama: Validation, discussion, Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Adams, M.D., 2020. Air pollution in Ontario, Canada during the COVID-19 state of emergency. Sci. Total Environ. 742, 140516. https://doi.org/10.1016/j.scitotenv.2020.140516.

AirVisual, I.Q., 2018. 2018 World Air Quality Report. https://www.iqair.com/world-most-polluted-cities/world-air-quality-report-2018-en.pdf/. (Accessed 28 October 2020).

Bao, R., Zhang, A., 2020. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. Sci. Total Environ. 731, 139052. https://doi.org/10.1016/j.scitotenv.2020.139052.

Briz-Redón, Á., Belenguer-Sapiña, C., Serrano-Aroca, Á., 2021. Changes in air pollution during COVID-19 lockdown in Spain: a multi-city study. J. Environ. Sci. (China) 101, 16–26. https://doi.org/10.1016/j.jes.2020.07.029.

Caraka, R.E., et al., 2020. Impact of COVID-19 large scale restriction on environment and economy in Indonesia. Global Journal of Environmental Science and Management 6 (Special Issue), 65–84. https://doi.org/10.22034/GJESM.2019.06.SI.07.

Chen, L.W.A., et al., 2020. Nonuniform impacts of COVID-19 lockdown on air quality over the United States. Sci. Total Environ. 745, 141105. https://doi.org/10.1016/j.scitotenv.2020.141105.

CNBC Indonesia, 2020. Coal Consumption in Indonesia Increased 59 Tons during Lockdown. https://www.cnbcindonesia.com/news/20200813102949-4-179477/ada-psbb-konsumsi-batubara-pln-capai-59-juta-ton-di-juli/. (Accessed 29 October 2020).

COVID-19 community mobility reports, 2020. See how your community is moving around differently due to COVID-19. https://www.google.com/covid19/mobility/?hl=en-GB. (Accessed 2 February 2021).

DKI Jakarta Department of Statistic, 2020. DKI Jakarta Statistics Report. https://jakarta.bps.go.id/. (Accessed 28 October 2020).

DKI Jakarta Governor Regulation No, 2020. About PSBB implementation in DKI jakarta, 33/.

DKI Jakarta Governor Regulation No, 2020. About health protocols and guidelines for workplace during transitional PSBB, 51/.

El-Magd, I.A., Zanaty, N., 2020. Impacts of short-term lockdown during COVID-19 on air quality in Egypt. The Egyptian Journal of REMOTE SENSING AND SPACE SCIENCES, 075003. https://doi.org/10.1016/j.ejrs.2020.10.003.

Farda, M., Balijepalli, C., 2018. Exploring the effectiveness of demand management policy in reducing traffic congestion and environmental pollution: car-free day and odd-even plate measures for Bandung city in Indonesia. Case Studies on Transport Policy 6 (4), 577–590. https://doi.org/10.1016/j.cstp.2018.07.008.

Frank, L.D., Engelke, P., 2005. Multiple impacts of the built environment on public health: walkable places and the exposure to air pollution. Int. Reg. Sci. Rev. 28 (2), 193–216. https://doi.org/10.1177/0160017604273853.

Gunawan, H., et al., 2017. Incorporating air quality improvement at a local level into climate policy in the transport sector: a case study in Bandung City, Indonesia. Environments–MDPI. 4 (3), 1–17. https://doi.org/10.3390/environments4030045.

Hashim, B.M., et al., 2021. Impact of COVID-19 lockdown on NO2, O3, PM2.5 and PM10 concentrations and assessing air quality changes in Baghdad, Iraq. Sci. Total Environ. 754, 141978. https://doi.org/10.1016/j.scitotenv.2020.141978.

Health Effects Institute, 2010. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. https://www.healtheffects.org/publication/traffic-related-air-pollution-critical-review-literature-emissions-exposure-and-health/. (Accessed 28 October 2020).
Indonesia Automotive Industries Association, 2020. Indonesian automobile industry production. https://www.gaikindo.or.id/indonesian-automobile-industry-data/. (Accessed 3 February 2021).
Indonesian COVID Handling Committee, 2020. The Indonesian Government Evaluate the Overall PSBB Implementation. https://covid19.go.id/p/berita/pemerintah-evaluasi-pelaksanaan-psbb-secara-menyeluruh. (Accessed 3 February 2021).
Indonesian Department of Statistics, 2018. Manufacturing Production Statistics in 2018. https://www.bps.go.id/publication/2020/10/20/2eadeb3609a714209994a3d2/statistik-industri-manufaktur-produksi-2018-.html. (Accessed 3 February 2021).
Indonesian Department of Statistics, 2019. Number of Vehicles by Type in 1949-2018. https://www.bps.go.id/linkTableDinamis/view/id/1133/. (Accessed 29 October 2020).
Indonesian Ministry of Environment, 2010. Ministry of Environment Decision No: KEP 45/MENLH/1997. http://iku.menlhk.go.id/aqms/uploads/docs/ispu.pdf/. (Accessed 24 October 2020).
Indonesian Ministry of Health, 2020. PSBB Implementation Guidelines. https://covid19.go.id/storage/app/media/Regulasi/KisiKisiPelaksanaanPSBB.pdf/. (Accessed 29 October 2020).
Indonesian Ministry of Industry, 2020. Reports on Indonesia Industrial Development Year 2020. https://www.kemenperin.go.id/brosur. (Accessed 3 February 2021).
Kanniah, K.D., et al., 2020. COVID-19's impact on the atmospheric environment in the Southeast Asia region. Sci. Total Environ. 736, 139658. https://doi: 10.1016/j.scitotenv.2020.139658.
Kerimray, A., et al., 2020. Assessing air quality changes in large cities during COVID-19 lockdowns: the impacts of traffic-free urban conditions in Almaty, Kazakhstan. Sci. Total Environ. 730 https://doi.org/10.1016/j.scitotenv.2020.139179, 139179.
Kumari, P., Toshniwal, D., 2020. Impact of lockdown on air quality over major cities across the globe during COVID-19 pandemic. Urban Climate 34, 100719. https://doi.org/10.1016/j.uclim.2020.100719.
Lamarque, J.-F., et al., 2010. Historical (1850-2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application. Atmos. Chem. Phys. 10, 7017–7039 doi:10.5194/acp- 10-7017-2010, 2010.
Lelieveld, J., et al., 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525, 367–371. https://doi.org/10.1038/nature15371.
Mahato, S., Pal, S., Ghosh, K.G., 2020. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Sci. Total Environ. 730 https://doi.org/10.1016/j.scitotenv.2020.139086.
Marshall, J.D., et al., 2005. Inhalation of motor vehicle emissions: effects of urban population and land area. Atmos. Environ. 39 (2), 283–295. https://doi.org/10.1016/j.atmosenv.2004.09.059.
Mohtar, A.A.A., et al., 2018. Variation of major air pollutants in different seasonal conditions in an urban environment in Malaysia. Geoscience Letters 5 (1), 21. https://doi.org/10.1186/s40562-018-0122-y.
Norazian, M.N., et al., 2015. Variation of air pollutant (particulate matter-PM10) in peninsular Malaysia: study in the southwest coast of peninsular Malaysia. Rev. Chem. 66 (9), 1443–1447.
Otmani, A., et al., 2020. Impact of covid-19 lockdown on PM10, SO2 and NO2 concentrations in salé city (Morocco). Sci. Total Environ. 735, 139541. https://doi.org/10.1016/j.scitotenv.2020.139541.
Pei, Z., et al., 2020. Response of major air pollutants to COVID-19 lockdowns in China. Sci. Total Environ. 743, 140879. https://doi.org/10.1016/j.scitotenv.2020.140879.
Purnomo, M.R.A., Anugerah, A.R., 2020. Achieving sustainable environment through prediction of air pollutants in Yogyakarta using adaptive neuro fuzzy inference system. J. Eng. Sci. Technol. 15 (5), 2995–3012.
Rahman, M.S., et al., 2020. How air quality and COVID-19 transmission change under different lockdown scenarios? A case from Dhaka city, Bangladesh. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2020.143161.
Rizwan, S.A., Nongkynrih, B., Gupta, S.K., 2013. Air pollution in Delhi: its magnitude and effects on health. Indian J. Community Med. 38 (1), 4–8. https://doi.org/10.4103/0970-0218.106617.
Ropkins, K., Tate, J.E., 2021. Early observations on the impact of the COVID-19 lockdown on air quality trends across the UK. Sci. Total Environ. 754, 142374. https://doi.org/10.1016/j.scitotenv.2020.142374.
Saari, U.A., et al., 2020. How consumers' respect for nature and environmental self-assets influence their car brand experiences. J. Clean. Prod. 261, 121023. https://doi.org/10.1016/j.jclepro.2020.121023.
Selvam, S., et al., 2020. Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin, South India: a revival perspective. Sci. Total Environ. 738, 139848. https://doi.org/10.1016/j.scitotenv.2020.139848.
Shakoor, A., et al., 2020. Fluctuations in environmental pollutants and air quality during the lockdown in the USA and China: two sides of COVID-19 pandemic. Air Quality, Atmosphere & Health 13 (11), 1335–1342. https://doi.org/10.1007/s11869-020-00888-6.
Statista, 2020. Average PM2.5 Concentration of the Most Polluted Capital Cities in the World in 2019. Energy & Environment Services. https://www.statista.com/statistics/1135370/most-polluted-capital-cities-in-the-world/. (Accessed 29 October 2020).
Strategies, Vital, 2020. Towards Clean Air Jakarta. https://www.vitalstrategies.org/resources/toward-clean-air-jakarta-improving-air-quality-in-jakarta-in-the-near-and-long-term/. (Accessed 28 October 2020).
The INRIX Global Traffic Scorecard, 2019. INRIX 2019 Global Traffic Scorecard. https://inrix.com/scorecard/. (Accessed 2 February 2021).
Tomtom Traffic Index, 2020. Jakarta traffic in 2020. https://www.tomtom.com/en_gb/traffic-index/jakarta-traffic. (Accessed 2 February 2021).
Viva News, 2019. Most Polluted Companies in DKI Jakarta. https://www.viva.co.id/berita/metro/1173423-daftar-perusahaan-penyumbang-polusi-udara-jakarta. (Accessed 3 February 2021).
Wang, Pengfei, et al., 2020. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resour. Conserv. Recycl. 158, 104814. https://doi.org/10.1016/j.resconrec.2020.104814.
World Health Organization (WHO), 2020. Coronavirus Disease 2019 (COVID-19) Situation Report. World Health Organization. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200323-sitrep-63-covid-19.pdf?sfvrsn=b617302d_4/. (Accessed 28 October 2020).
World Population Review, 2020. 2019 World Population by Country. https://worldpopulationreview.com/. (Accessed 29 October 2020).
Zambrano-Monserrate, M.A., Ruano, M.A., 2020. Has air quality improved in Ecuador during the COVID-19 pandemic? A parametric analysis. Air Quality, Atmosphere and Health 13, 929–938. https://doi.org/10.1007/s11869-020-00866-y.